TITLE: Implementation of New Materials on Aging Aircraft Structure

Implementation of New Materials on Aging Aircraft Structure

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Numerous advances in new materials such as aluminum-lithium alloys, discontinuously reinforced aluminum composites, elevated temperature alloys, and other materials have occurred over the last several decades by academia, industry, and government laboratories around the world. However, implementation of these materials for primary aircraft structure have been infrequent due to several key issues, including alloy suitability for the required service environment, deficiencies in microstructure/properties, implementation timing, as well as end-user/customer acceptance of new materials. Two material systems that have been implemented through a team of Lockheed Martin Tactical Aircraft Systems, DWA Aluminum Composites,McCook Metals Ltd (formerly Reynolds Metals Co.), and U.S. Air Force engineers include 6092/SiC/17.5p-T6 Discontinuously Reinforced Aluminum (DRA) sheet and 2297-T861 Aluminum-Lithium plate. This paper provides a background on successful technology transitions in the commercial sector, descriptions of the development and building-block testing of the DRA and AlLi materials, and lessons learned on the successful implementation of these two materials on existing aircraft structure.

Introduction

High performance aircraft require a myriad of materials technologies to meet the performance, weight, and affordability standards required by the end-user. Over the past thirty years, the number of new materials systems that the materials industry designs has surpassed the available resources to qualify and/or implement these materials into aircraft. Some systems did not live up to the projected expectations. Early disappointments with aluminum alloys containing relatively high lithium contents (>2%) created a significant impediment to qualifying new lithium containing alloys. Similarly, reinforced powder metallurgy alloys experienced several early set-backs arising from scale-up and property shortfalls in the area of fracture toughness. High temperature aluminum alloys have not yet enjoyed the success of high volume usage on aircraft systems. In general terms, the road to implementation seems rather long, as illustrated in Table 1. ("Bringing New Materials to Market", Tech. Review, Feb/Mar 1995, pp43-49)

Paper prepared for the RTO AVT Workshop on "New Metallic Materials for the Structure of Aging Aircraft", held in Corfu, Greece, 19-20 April 1999, and published in RTO MP-25.

Table 0-1. 20 Years from Invention to Commercialization

Materials Technology	Invention	Widespread Commercialization
Vulcanized Rubber	1839	Late 1850's
Low-Cost Aluminum	1886	Early 1900's
Teflon	1938	Early 1960's
Titanium (Structural Uses)	Mid 1940's	Early 1960's
Velcro	Early 1950's	Early 1970's
Polycarbonate (Bullet Proof Glass)	1953	About 1970
Gallium Arsenide	Mid 1960's	Mid 1980's
Diamond-Like Thin Films	Early 1990's	Early 1990's
Amorphous Soft Magnetic Materials	Early 1990's	Early 1990's

With the materials in Table 1, it took on average twenty years from invention to widespread commercialization. Today, materials producers can expect a ten year cycle to fully qualify a material system for structural applications. As mentioned previously, several new systems that showed promise were dropped from implementation consideration. Figure 1 shows a schematic criteria map for materials from initial research and development through production implementation.

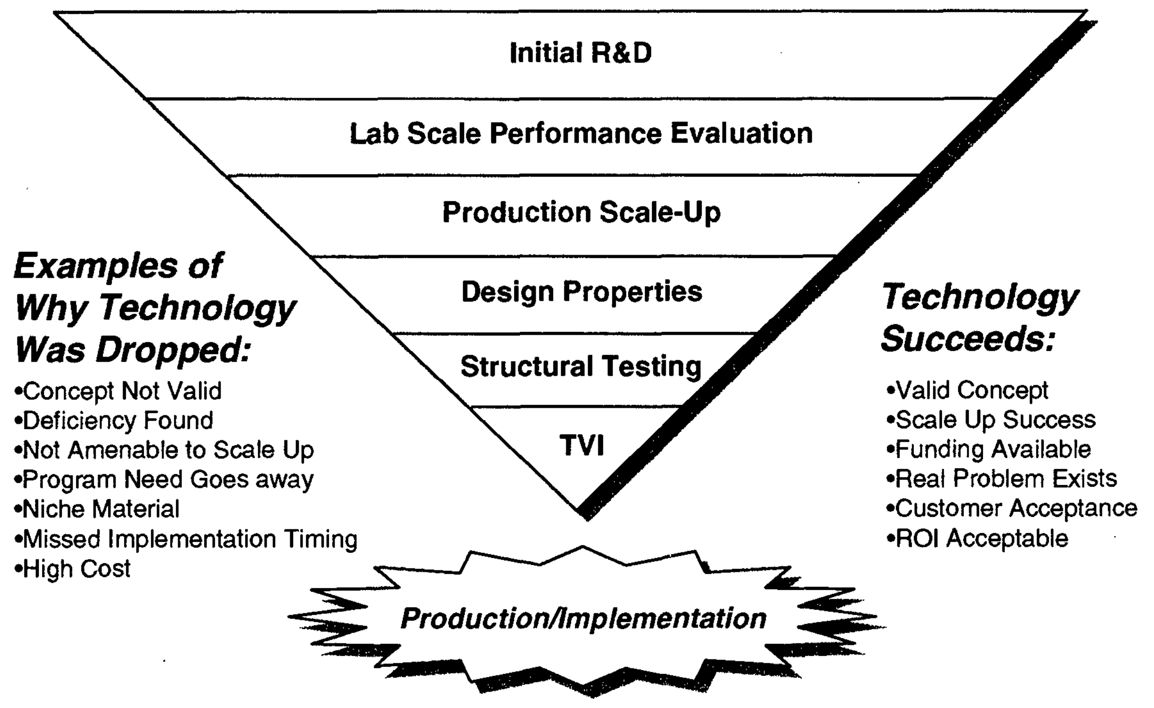


Figure 0-1. Examples of Techology Downselection Criteria

The list of materials implementation challenges seems rather ominous, however, successful implementation of new materials have occurred recently on Lockheed Martin fighter aircraft. These technology insertion opportunities have been an excellent example of industry/government/producer team work. The materials for discussion include a moderate strength Al-Li alloy (2297) and a moderate strength discontinuously reinforced aluminum alloy (6092/17.5p/SiC). Each of these materials are in either full-scale production or are in the process of being qualified for a Lockheed Martin Tactical Aircraft System aircraft.

Discussion

Al-Li Alloy 2297

2297 was initially developed in 1988 under a cooperative research arrangement between Lockheed Martin and McCook Metals, LLC (formerly Reynolds Metals). The impetus for the development was to produce a thick section, reduced density material that had the strength, thermal stability, fracture toughness, isotropy, and corrosion resistance of 2124 plate alloys up to 6 inches. While organic composites have eclipsed metals in two dimensional loading applications such as fighter aircraft skins, acceptable composites for three dimensional loading has proven to be a difficult challenge. Therefore, investing in new metallic structure for highly loaded bulkheads seemed a promising area of research and development. Following several years of alloy development, coupon testing, corrosion testing, and scale-up activities, structural testing was conducted on the main landing gear bulkhead for the F-16 Block 25. Figure 2 shows the outstanding spectrum fatigue behavior demonstrated in the full scale test articles.

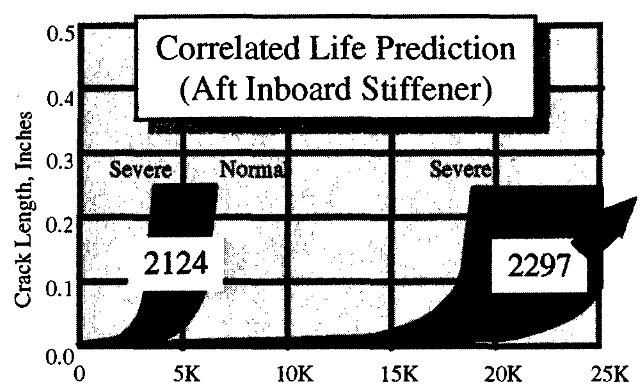


Figure 0-2. F-16 Bulkhead Spectrum Fatigue Results for 2297 Plate

Another key aspect of this testing was to demonstrate that the material behavior was congruent with current fatigue life prediction methodologies. As shown in Figure 3, the coupon testing and component testing resulted in higher stressallowables for the 2297 material compared to even higher strength alloys like 7050-T7451.

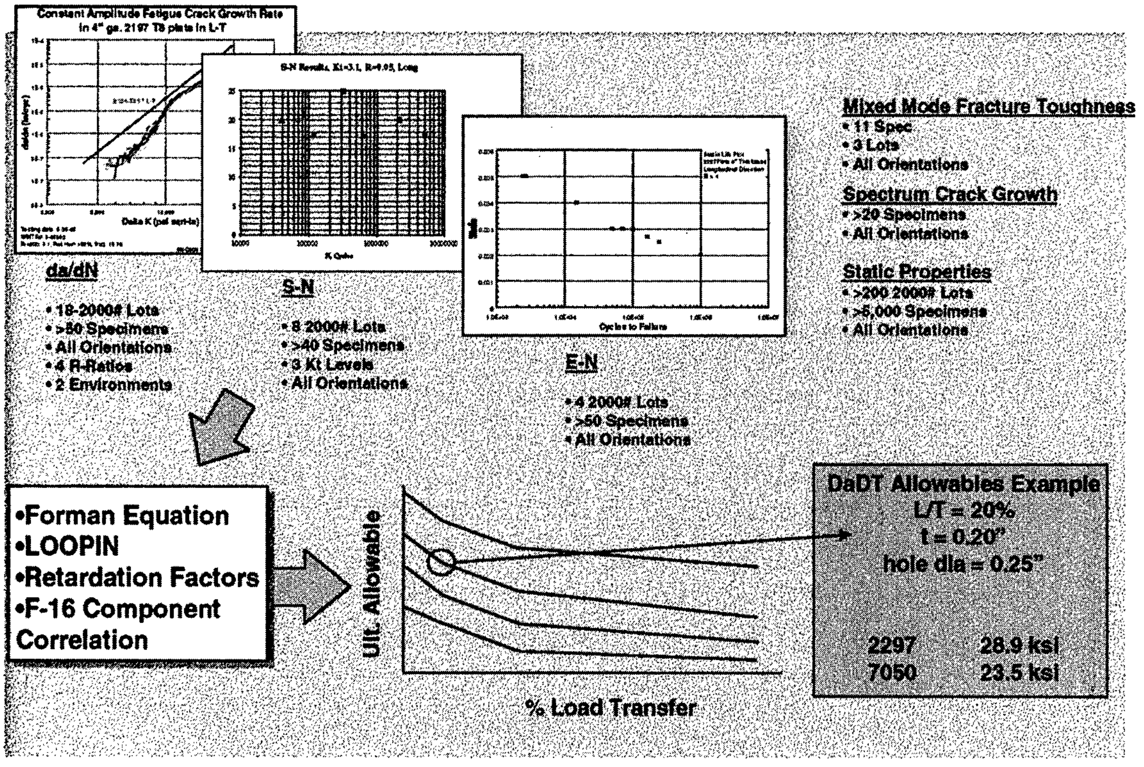


Figure 0-3. 2297 Demonstrated Predicable Fatigue Performance

In addition to the main landing gear bulkhead component testing, full-scale aircraft strain surveys and flight evaluation was conducted at Hill Air Force Base as shown in Figure 4.

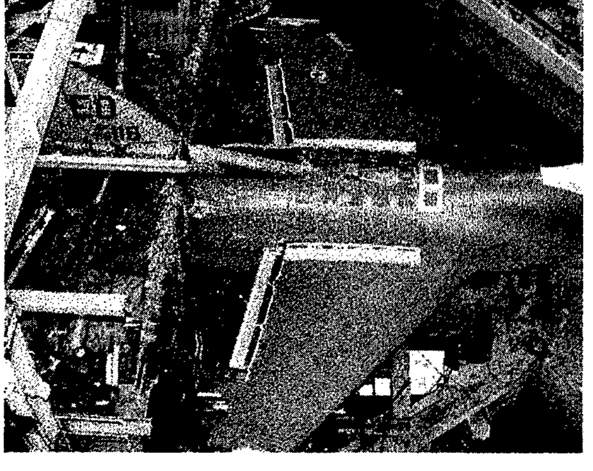


Figure 0-4. Strain Survey of Al-Li Bulkhead at Lockheed Martin TAS

All of the testing was successful and resulted in additional testing for other bulkhead applications such as the aft-most bulkhead on pre-block 40 F-16's as shown in Figure 5. Testing of this bulkhead in a fully-reversed aircraft spectrum resulted in similar 3 to 5X life improvements as shown in Figure 2.

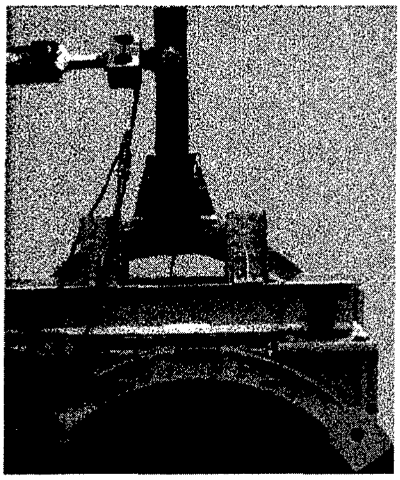


Figure 0-5. Aft Bulkhead Spectrum Fatigue Testing.

As a result of this successful product development program, over 2 million pounds of 2297 plate have been manufactured for use on F-16 spares and new production. ROI discussions will be provided in a later section.

6092/17.5p/SiC Discontinuously Reinforced Aluminum

At the same time as the development of the Al-Li alloy, Lockheed Martin was pursuing high stiffness materials for use in secondary structure applications. DRA materials produced via the powder metallurgy route as shown in Figure 6, offertailorable properties depending on reinforcement type and amount.

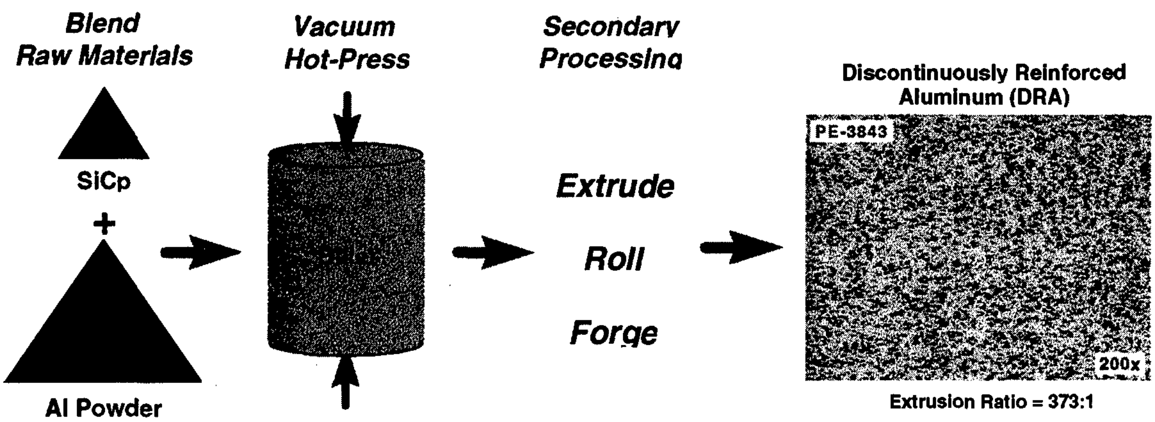
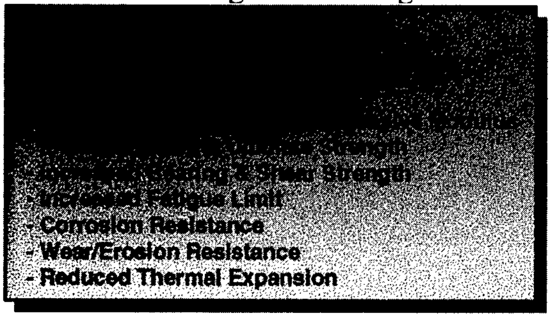
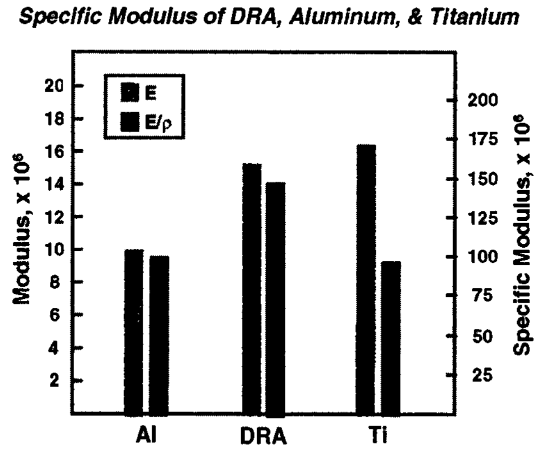


Figure 0-6. DRA Processing Schematic

Other DRA materials have been developed over the years, but the toughness and elongation-to-failure were always a concern for safety-of-flight applications. Lockheed Martin and DWA Aluminum Composites participated in a joint development program to produce a moderate strength, higher toughness material that would meet most secondary structure applications. Following a successful development effort, the 6092 chemistry was selected for scale-up under a "Title III" program under Air Force direction. The Title III program provided allowables testing, fatigue testing, and corrosion testing of production material to provide an "on-ramp" for production applications. Alloy benefits are summarized in Figures 7 through 9.





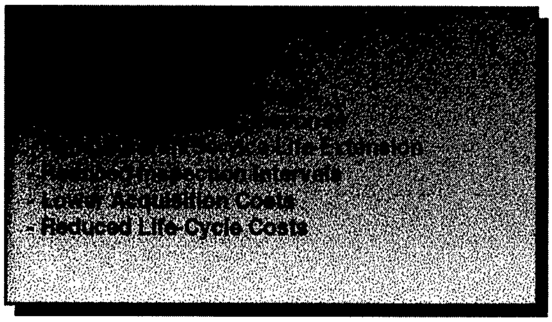


Figure 0-7. DRA Benefits

Material System	6092/SiC/17.5p	6092/SiC/17.5p	6092/SiC/17.5p	6092/SiC/17.5p	6092/SiC/17.5p
Form	Sheet	Sheet	Sheet	Sheet	Sheet
Temper	T-6	T-6	T-6	T-6	T-6
Thickness (in)	.040	.060	.080	.100	.125
Density	.101 lb/in^3	.101 lb/in^3	.101 lb/in^3	.101 lb/in^3	.101 lb/in^3
Basis	Average	Average	Average	Average	Average
F, tu (ksi)					
L	69	67	66	67	67
LT	66	65	65	66	70
F, ty (ksi)					
L	58	58	56	57	57
LT	54	52	52	53	53
F, cy (ksi)					
L	71	66	56	59	62
LT	66	63	56	56	59
F, su (ksi)					
L	44	43	42	42	43
LT	44	43	42	42	42
F, bru (ksi)					
L, (e/D= 1.5) ..	119	118	109	106	107
L, (e/D= 2.0)...	157	150	144	139	140
LT, (e/D= 1.5)..	117	114	108	110	104
LT, (e/D= 2.0)..	156	152	142	139	136
F, bry (ksi)					
L, (e/D= 1.5) ..	117	116	101	100	100
L, (e/D= 2.0)...	147	144	125	124	122
LT, (e/D= 1.5)..	116	112	100	101	95
LT, (e/D= 2.0)..	147	145	123	122	119
e, (percent)					
L	7	8	8	8	8
LT	7	8	8	7	8
E, t (msi)					
L	14.6	14.7	14.7	14.7	14.7
LT	14.7	14.4	14.7	14.7	14.7
E, c (msi)					
L	14.1	14.3	14.3	14.5	14.1
LT	13.9	14.0	14.0	14.5	14.2
CTE, (ppm/°F)					
L	9.3	9.4	9.3	9.1	9.3
LT	9.1	9.2	9.2	9.4	9.1

Figure 0-8. DRA Mechanical Properties

Figure 0-10. Flight Testing of DRA Ventral Fin at RNLAF

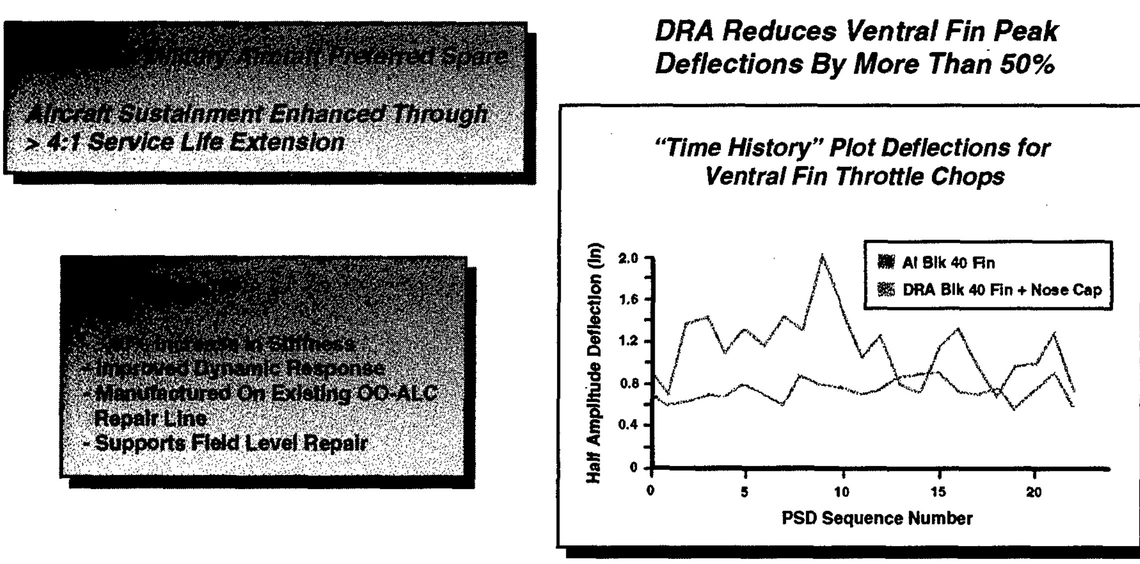


Figure 0-11. DRA Improved Dynamic Response of Ventral Fins

As a result of the successful flight testing on ventral fins, other opportunities to demonstrate the material's higher bearing allowable and higherstiffeness were successfully conducted. F-16 fuel access covers were flight tested inconjuntion with an improved fastening system and demonstrated as much as a 40% reduction in the peak stress levels on the F-16 upper skin as shown in Figure 12.

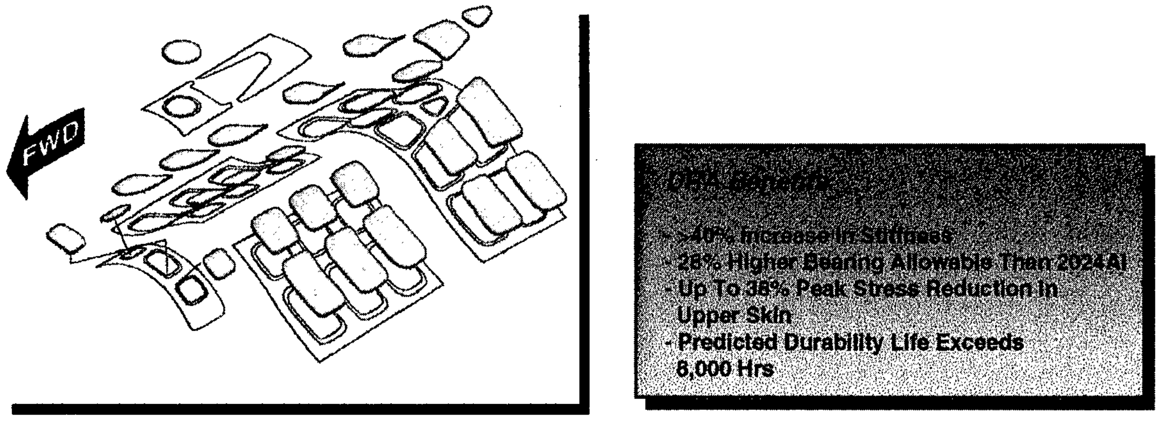


Figure 0-12. DRA Fuel Access Cover Benefits

As a result of these activities, over 200 shipsets of ventral fin skins have been produced at DWA Aluminum Composites for spares applications.

Cost Benefits Analysis

In each of the implementation efforts discussed, the material implementation would not have happened if the return on investment (ROI) was not financially sound. Figures 13-15 give the initial ROI estimates for these applications. The ROI has actually improved since material prices have fallen on both the 2297 and DRA materials once production quantities have been produced.

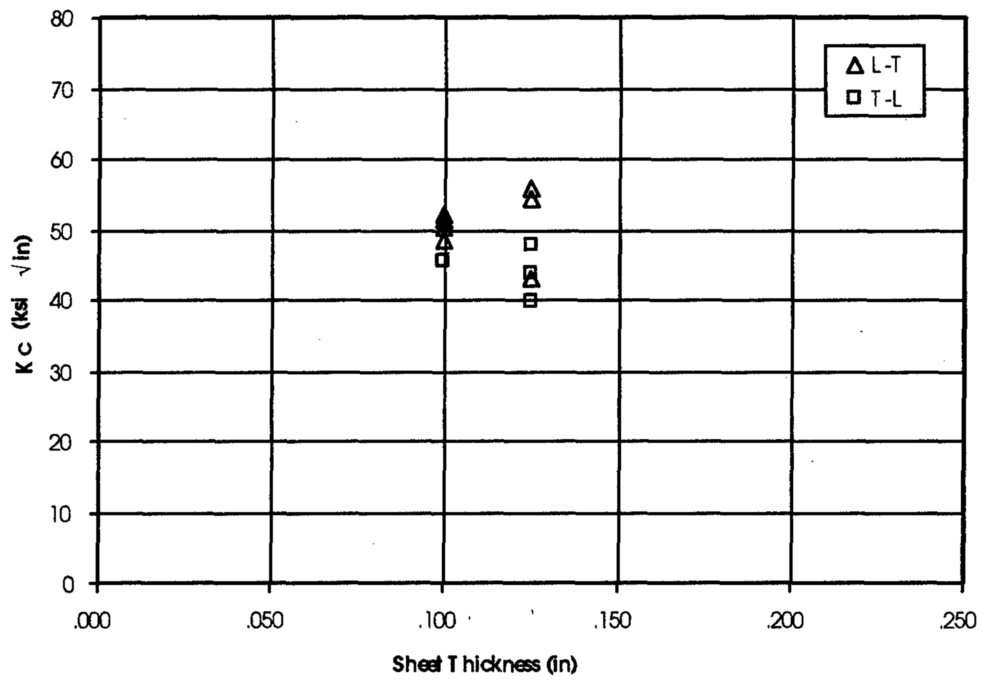


Figure 0-9. DRA Fracture Toughness

As a part of the Title III program, industry participants were selected to provide potential applications for testing and/or full-scale evaluation. LMTAS elected to demonstrate the material on F-16 ventral fin skin manufacturing. The ventral fins are subjected to a highly dynamic environment due to inlet spillage and the various stores arrangements typical in a fighter aircraft. Increasing the stiffness and aerodynamics of the ventral fin skins without increasing the weight, was empirically shown to provide a significant reduction in stress and increase in part life. Flight testing was conducted at the Royal Netherlands Air Force with the support of NLR to document the effect of utilizing DRA skins on a Block 15 aircraft as shown in Figure 10. Flight test results verified the empirical analysis and showed a 50% decrease in in-flight deflections (Figure 11).

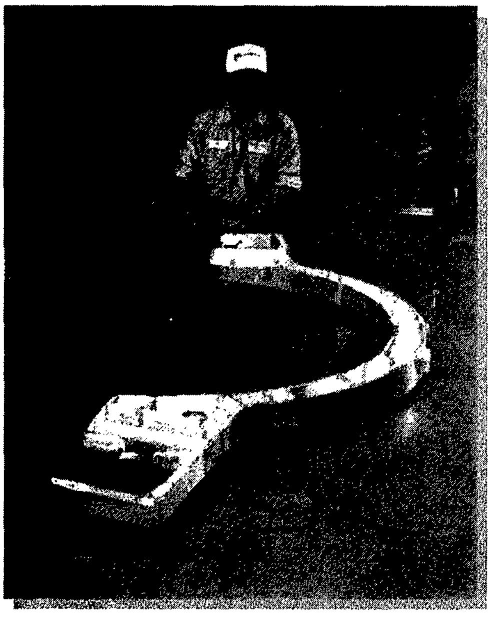
Spares Rework Costs at Depot	Current	New Design
Total Rework/Spares Cost	$3200	$6391

Maintenance Costs Analysis (8000 Hr Service Life)

Inspection	$66,900	$59,820
Maintenance/Replacement Cost	$16,000(5X)	$0 (0X)
Total Costs	$82,900	$59,820
Downtime Caused by Maintenance	2343 Mhrs	745 Mhrs

Projected Savings ⇨ $74,610,000-$53,838,000 = $20,772,000 (900 New Ventral Fins)

Figure 0-13. DRA Ventral Fin Cost Analysis



	2124	2X97
Cost To Replace		
Kit	$15K	$25K
Labor	$35K	$35K
Projected #	3X	1X
Total Fleet Cost (850 USAF)	$127.5M	$51M

Projected Cost Savings = $76.5M

Figure 0-14. 2297 Bulkhead Cost Analysis

CONCLUSIONS

Two successful materials implementation efforts have been described: 2297 Aluminum-Lithium plate products and 6092/17.5p/SiC Discontinuously Reinforced Aluminum. The success of both of these activities were a result of an industry/government/producer team that provided a viable material that was successfully scale-up to production quantities, provided predictable mechanical properties for design, was demonstrated in full-scale test articles, and was successfully applied to aircraft flight test efforts. The ROI for each material provided significant cost avoidance for the end-user.